



## Co-Electrolysis of Water and CO<sub>2</sub> for synthetic fuels

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*Publication date:*  
2013

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*Citation (APA):*

Jensen, S. H. (Author). (2013). Co-Electrolysis of Water and CO<sub>2</sub> for synthetic fuels. Sound/Visual production (digital) [http://www.natlab.dtu.dk/Energikonferencer/DTU\\_International\\_Energy\\_Conference\\_2013](http://www.natlab.dtu.dk/Energikonferencer/DTU_International_Energy_Conference_2013)

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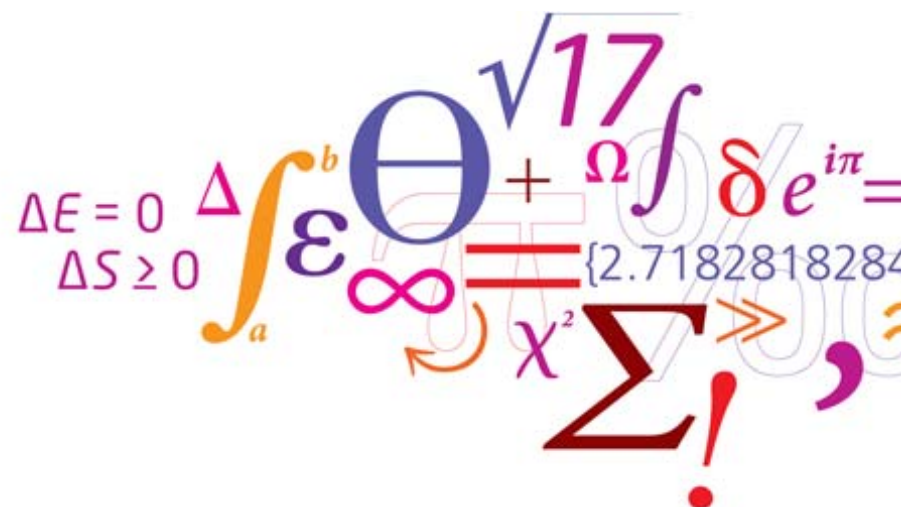
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# Co-Electrolysis of Water and CO<sub>2</sub> for synthetic fuels

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# Outline

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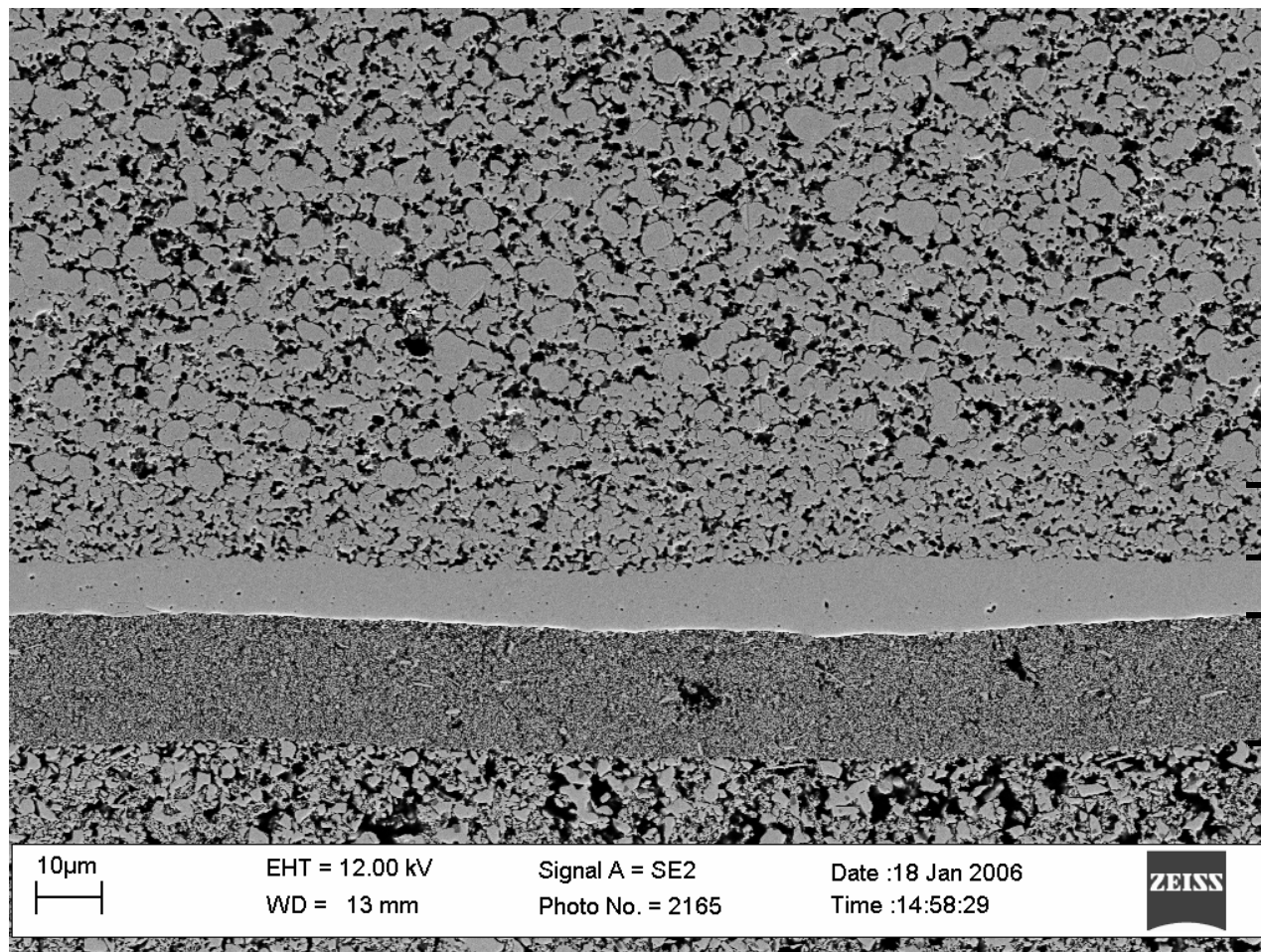
- 1. Solid Oxide Electrolyser Cell (SOEC)**
- 2. SOEC Electrode Potentials, Thermodynamic**
- 3. Gas Diffusion and Conversion**

# The Solid Oxide Cell

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# The Solid Oxide Cell



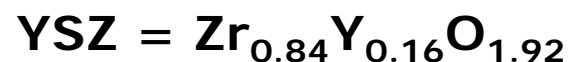
Ni-YSZ support  
& current  
collector

Ni-YSZ electrode

YSZ electrolyte

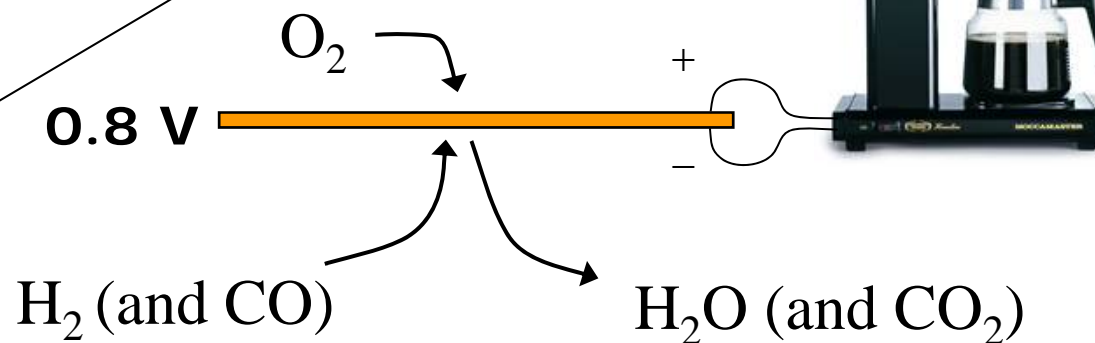
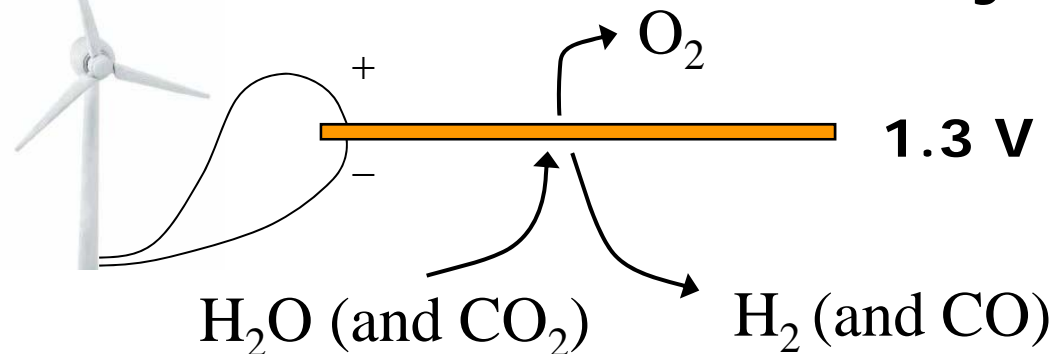
LSM-YSZ electrode

LSM current  
collector



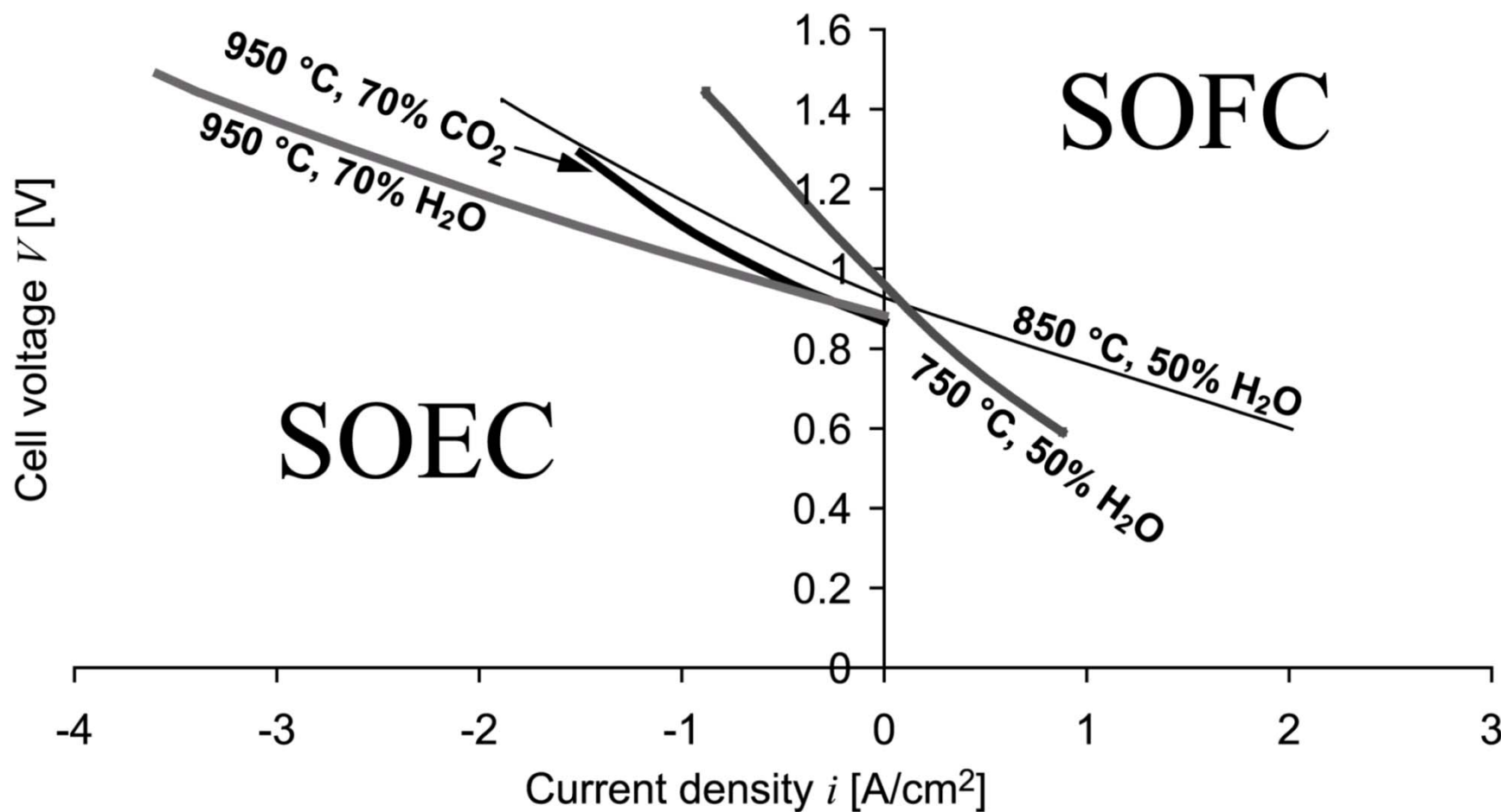
# The Solid Oxide Cell

## Solid Oxide Electrolysis Cell

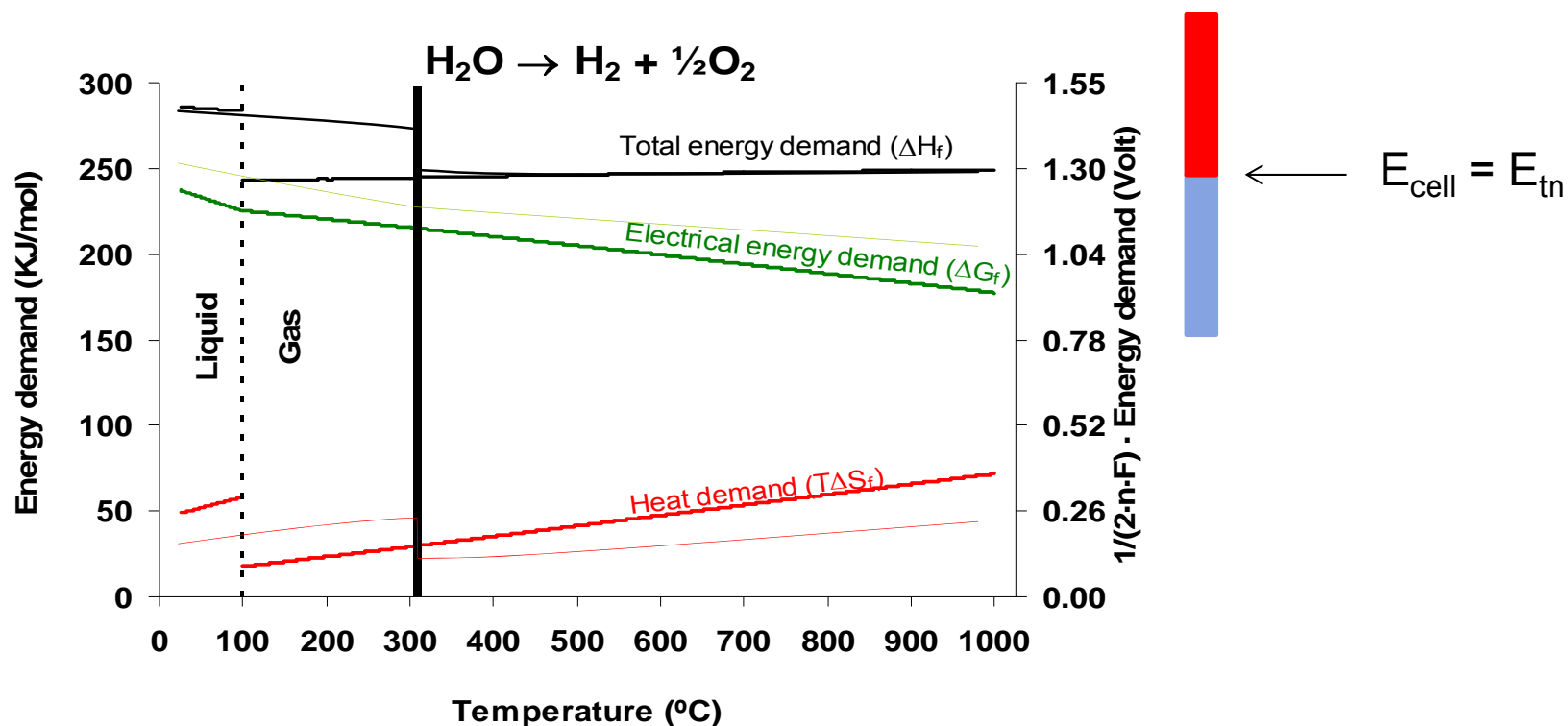


## Solid Oxide Fuel Cell

# The Solid Oxide Cell



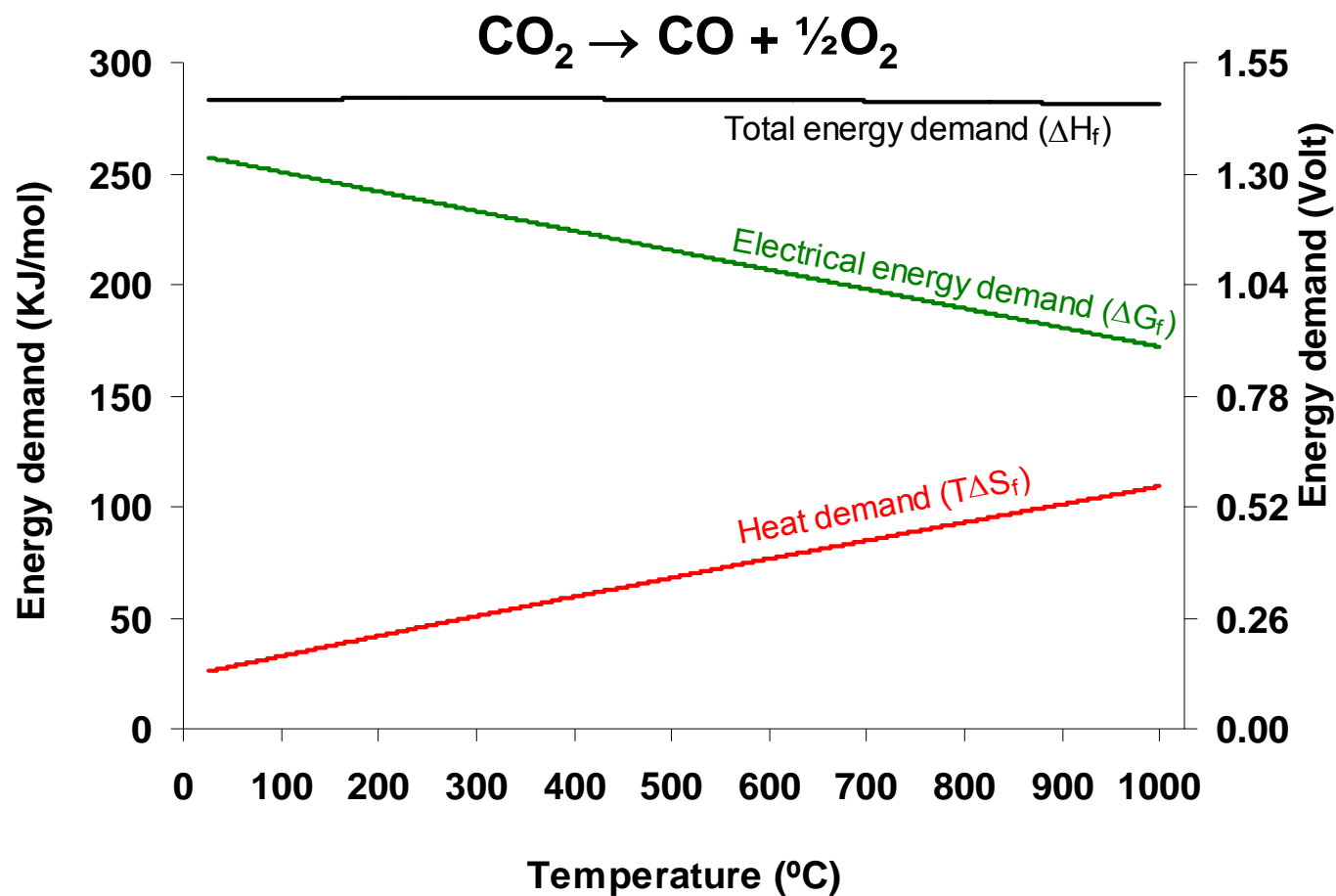
# Thermodynamics



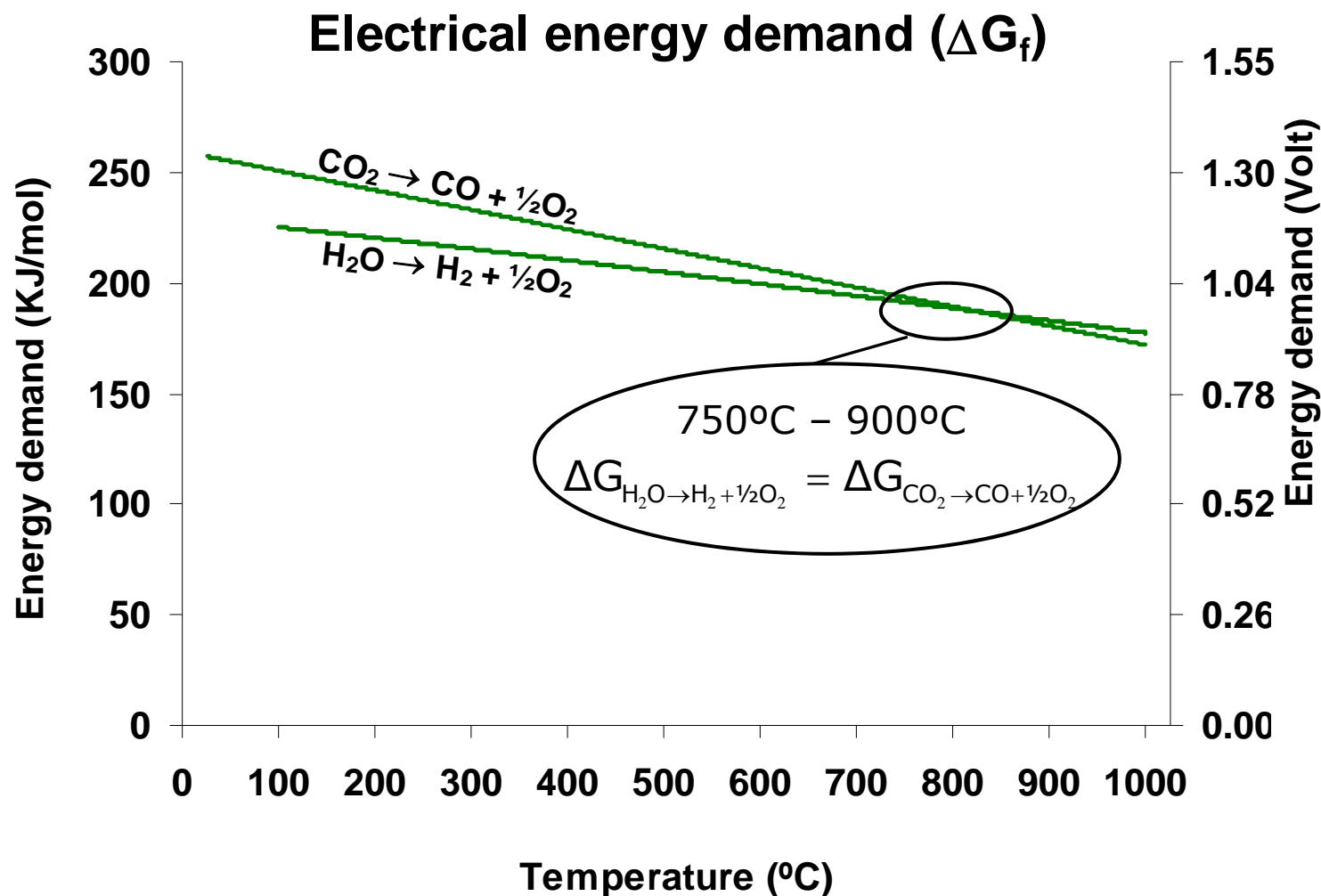
$$\eta = 100 \% \text{ at } E = E_{\text{tn}} \text{ (no heat loss)}$$



# Thermodynamics



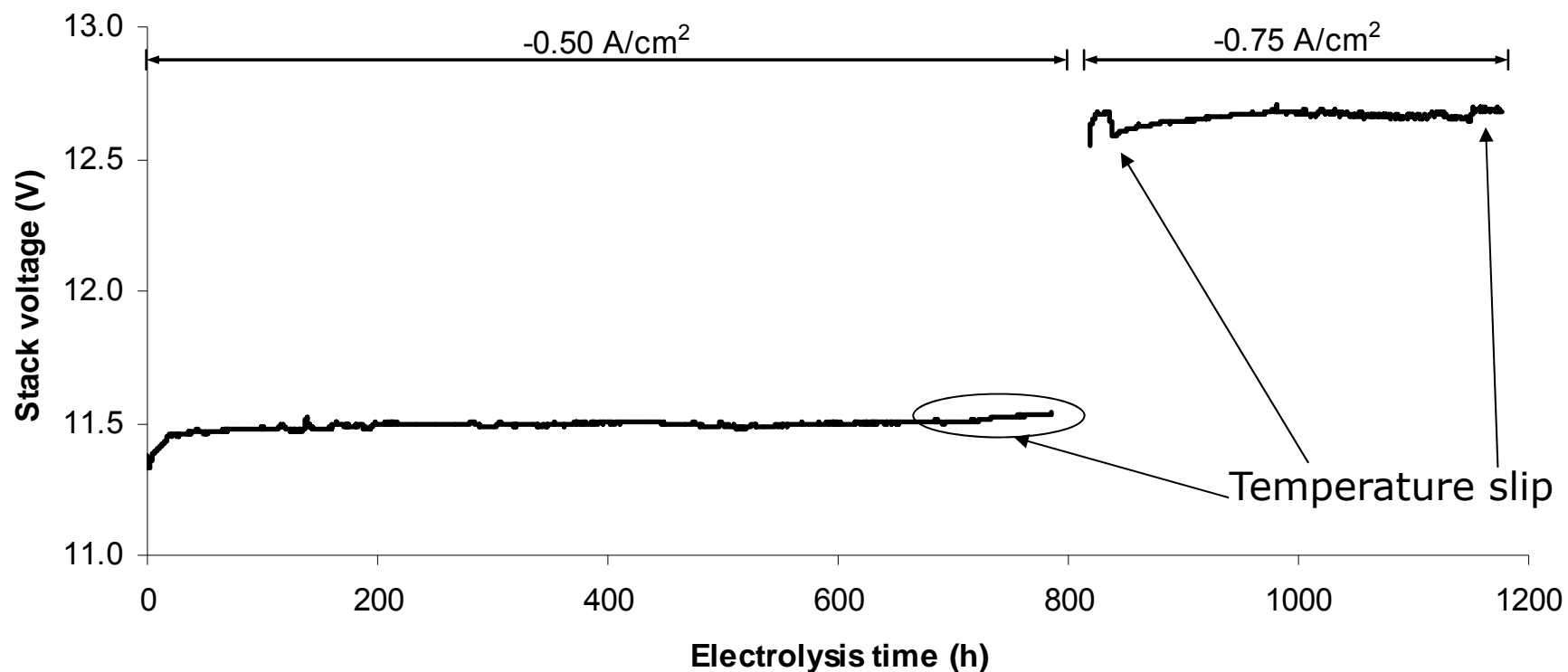
# Thermodynamics



# Co-electrolysis of H<sub>2</sub>O and CO<sub>2</sub>

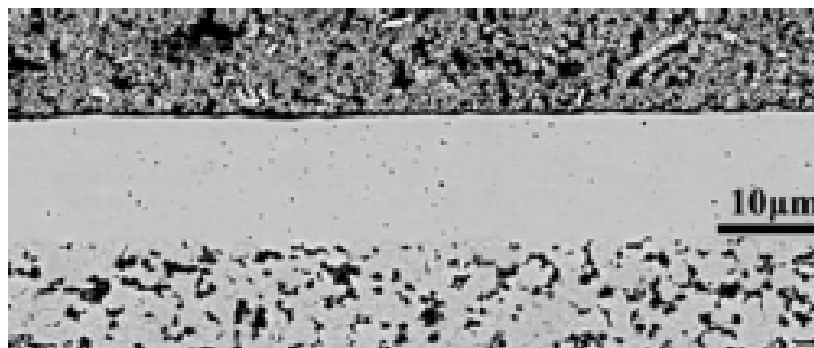
1 kW - 10-cell stack – 12 × 12 cm<sup>2</sup>

850 °C, -0.50 (-0.75) A/cm<sup>2</sup>, 45 % CO<sub>2</sub> / 45% H<sub>2</sub>O / 10 % H<sub>2</sub>

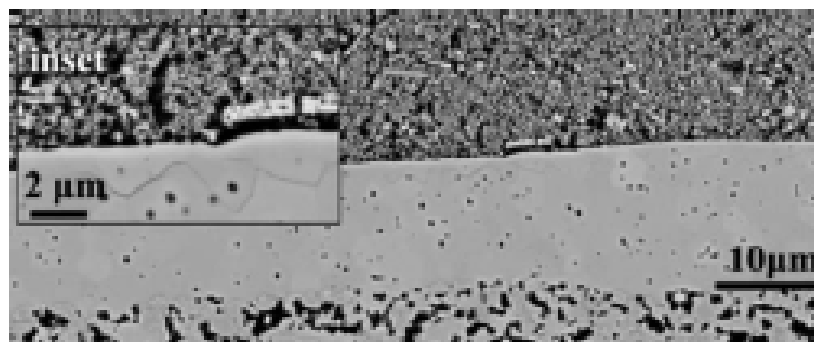


S. Ebbesen et al.

# Electrolyte degradation at high current



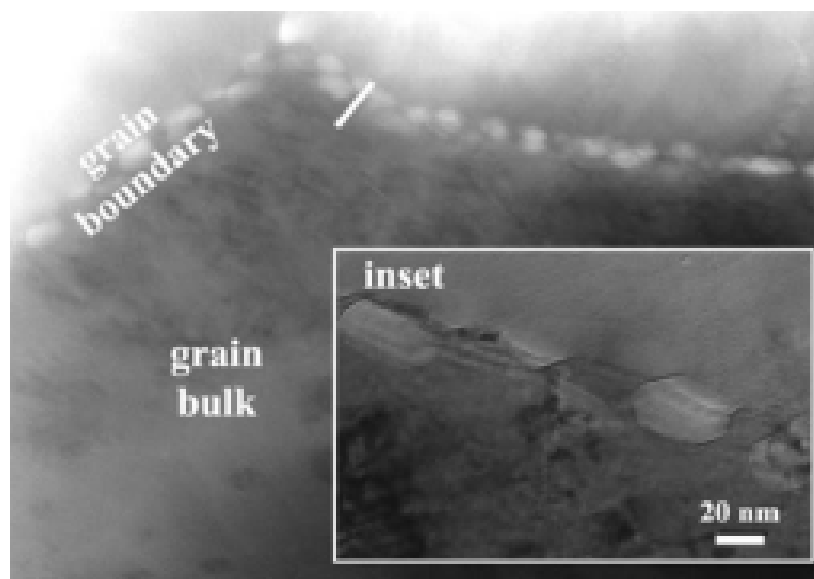
Cell with  $R_s$  constant  
(-1 A/cm<sup>2</sup>)



Cell with  $R_s$  increase  
(-2 A/cm<sup>2</sup>)

TEM study of the YSZ  
grain boundaries.... →

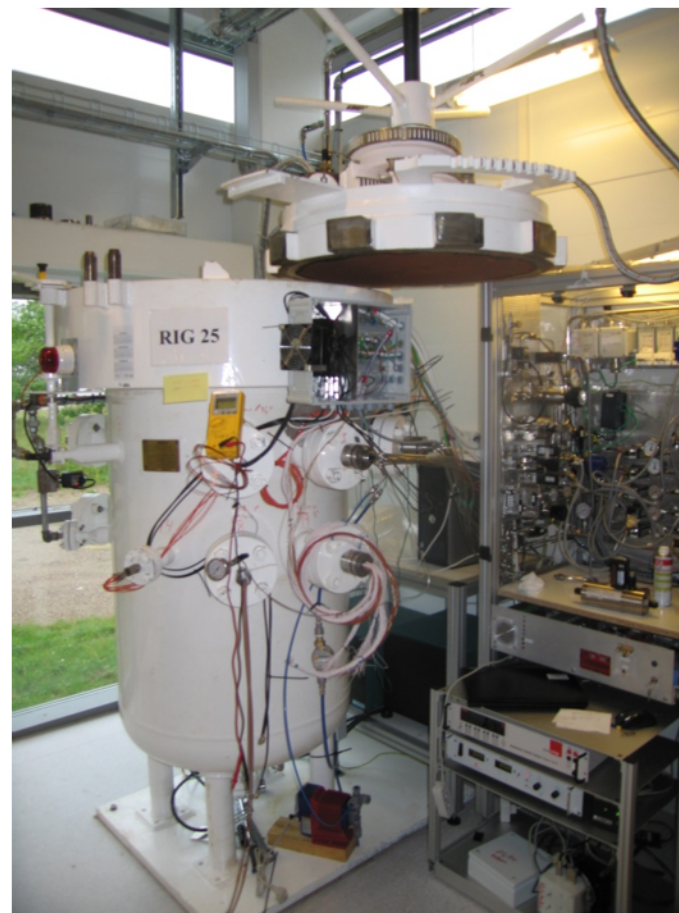
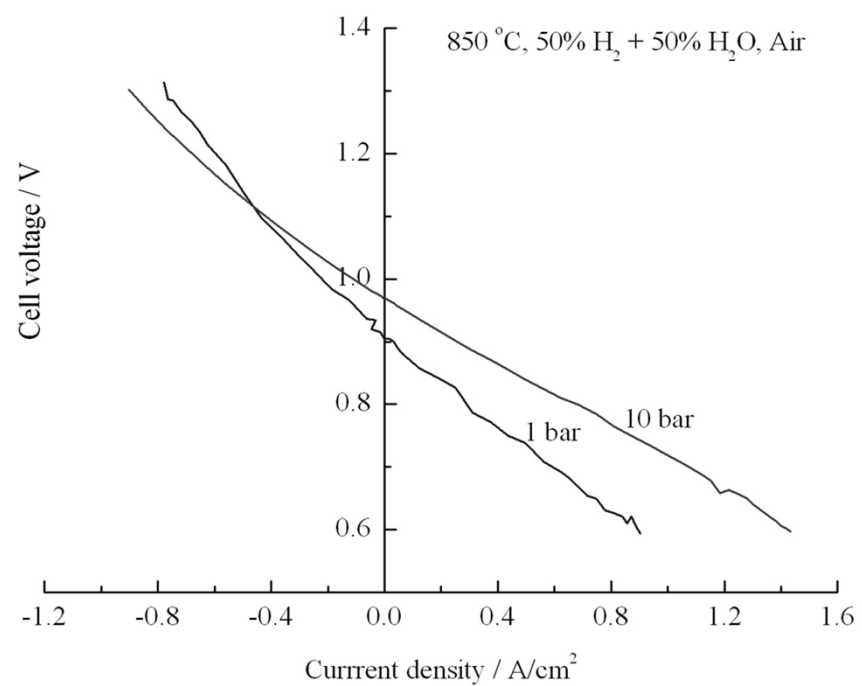
# Electrolyte degradation at high current



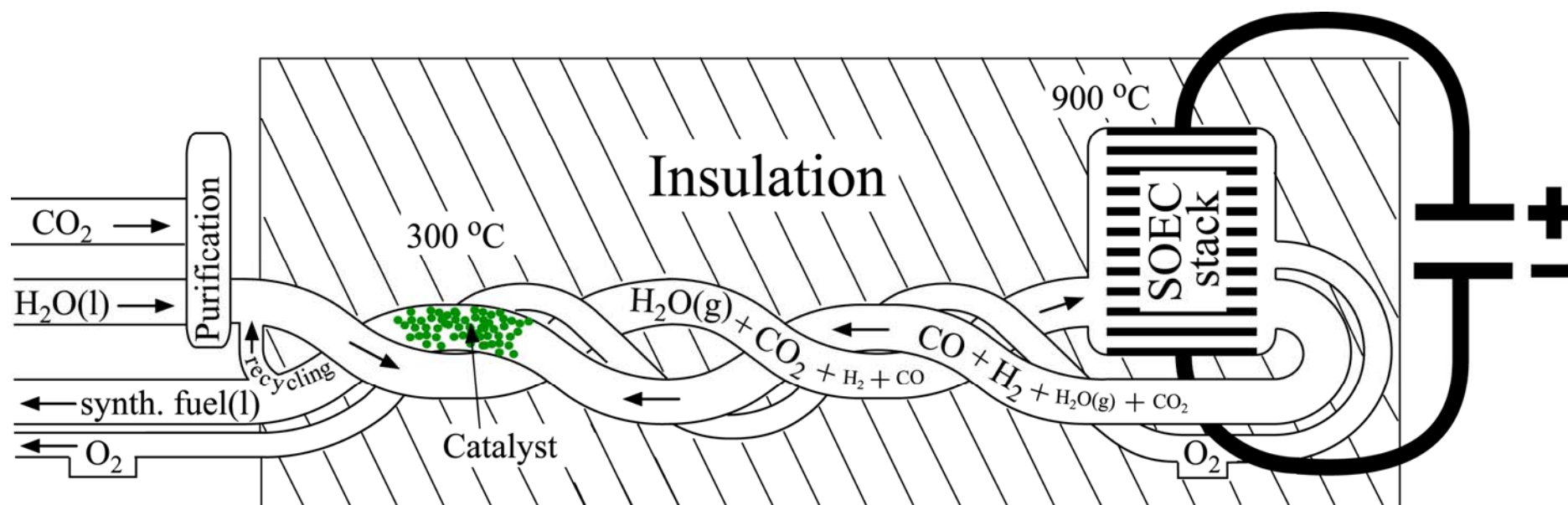
TEM of YSZ grain boundary near oxygen electrode from cell tested at  $-2 \text{ A/cm}^2$  ( $R_s$  increase)

Pore / gaps inbetween YSZ grains in the YSZ close to the electrolyte – oxygen electrode interface observed.

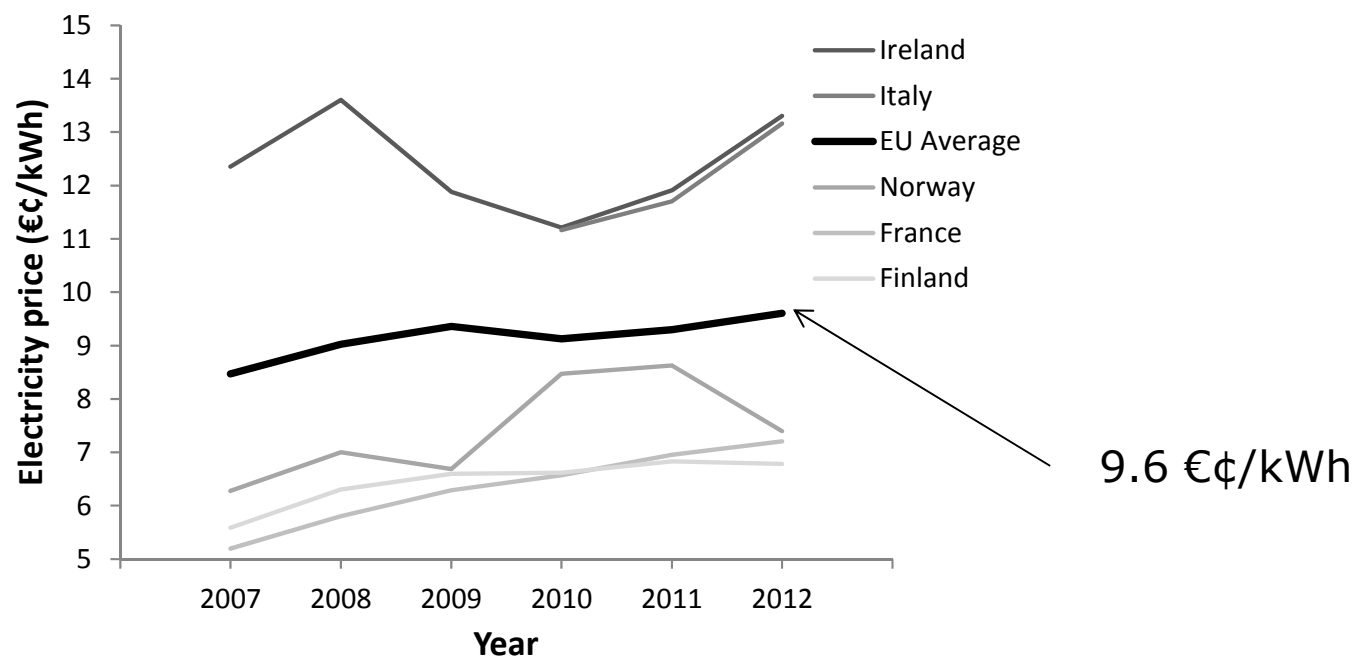
# The Pressure Test Setup



# Synthetic Fuel Production



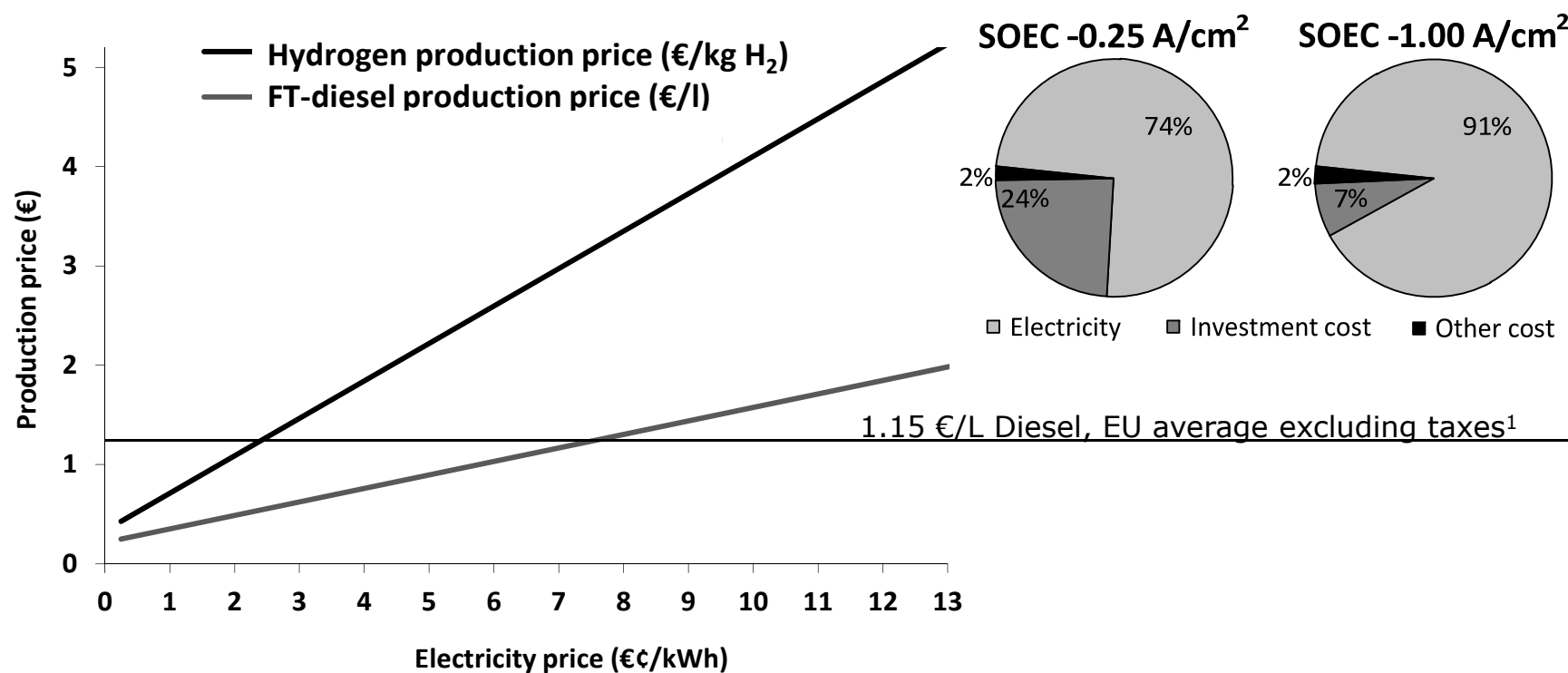
# Synthetic Fuel Production Economy



S. D. Ebbesen, S. H. Jensen, A. Hauch and M. Mogensen, to be submitted



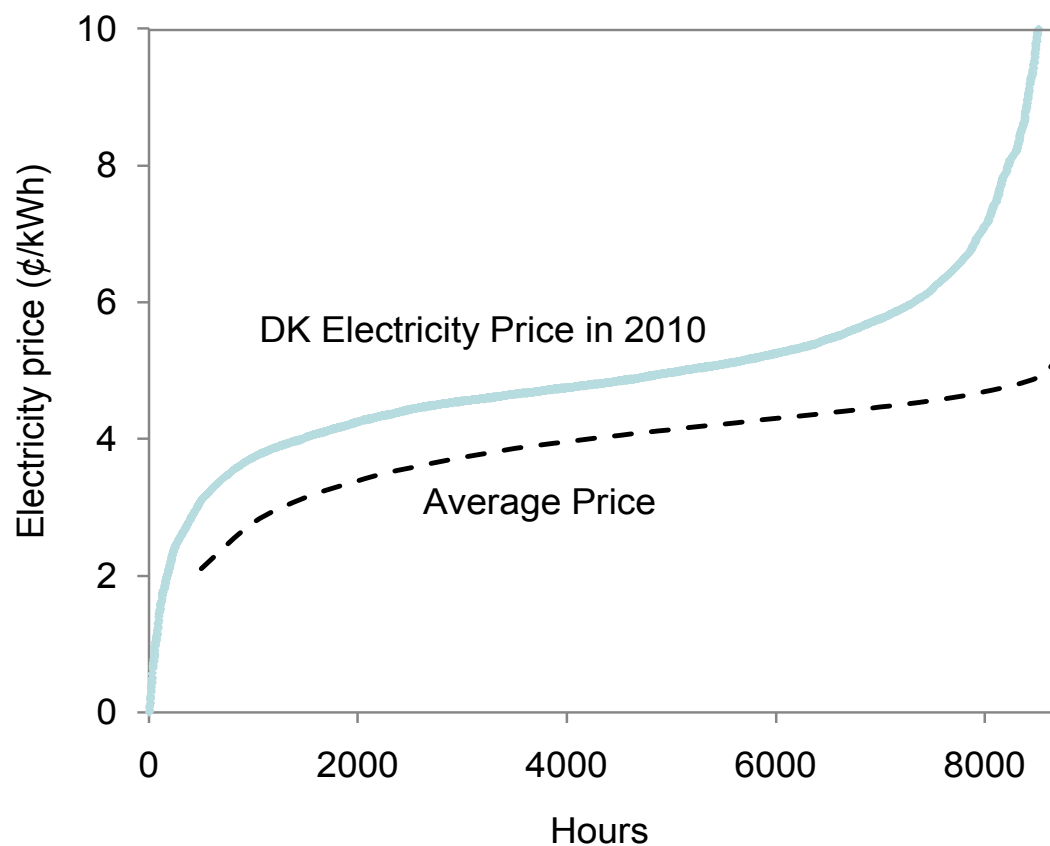
# Synthetic Fuel Production Economy



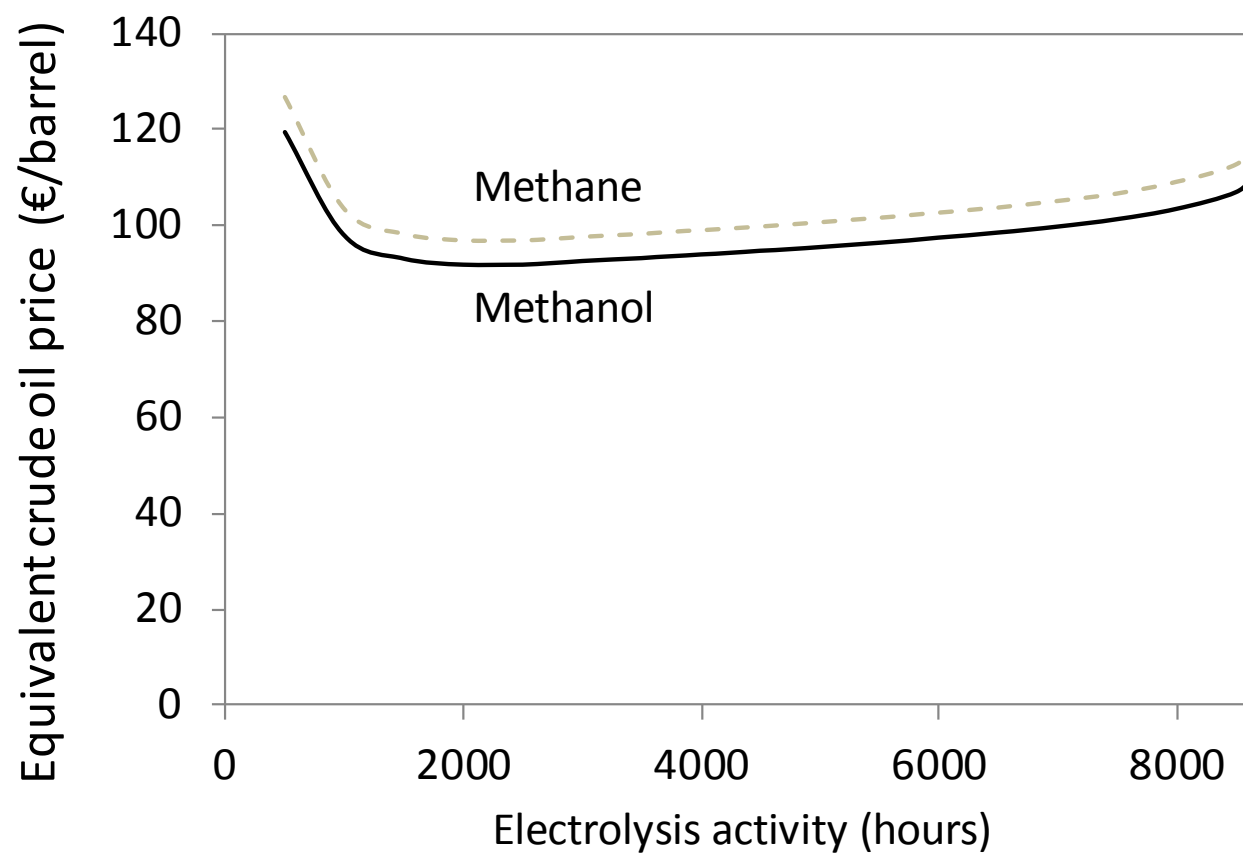
<sup>1</sup>Europe's Energy Portal. <http://www.energy.eu> . 2013

S. D. Ebbesen, S. H. Jensen, A. Hauch and M. Mogensen, to be submitted

# SOC Economy



# SOEC Economy



Søren Højgaard Jensen, Unpublished work

# WTI and BRENT Crude Oil price

WTI



BRENT



# Conclusions

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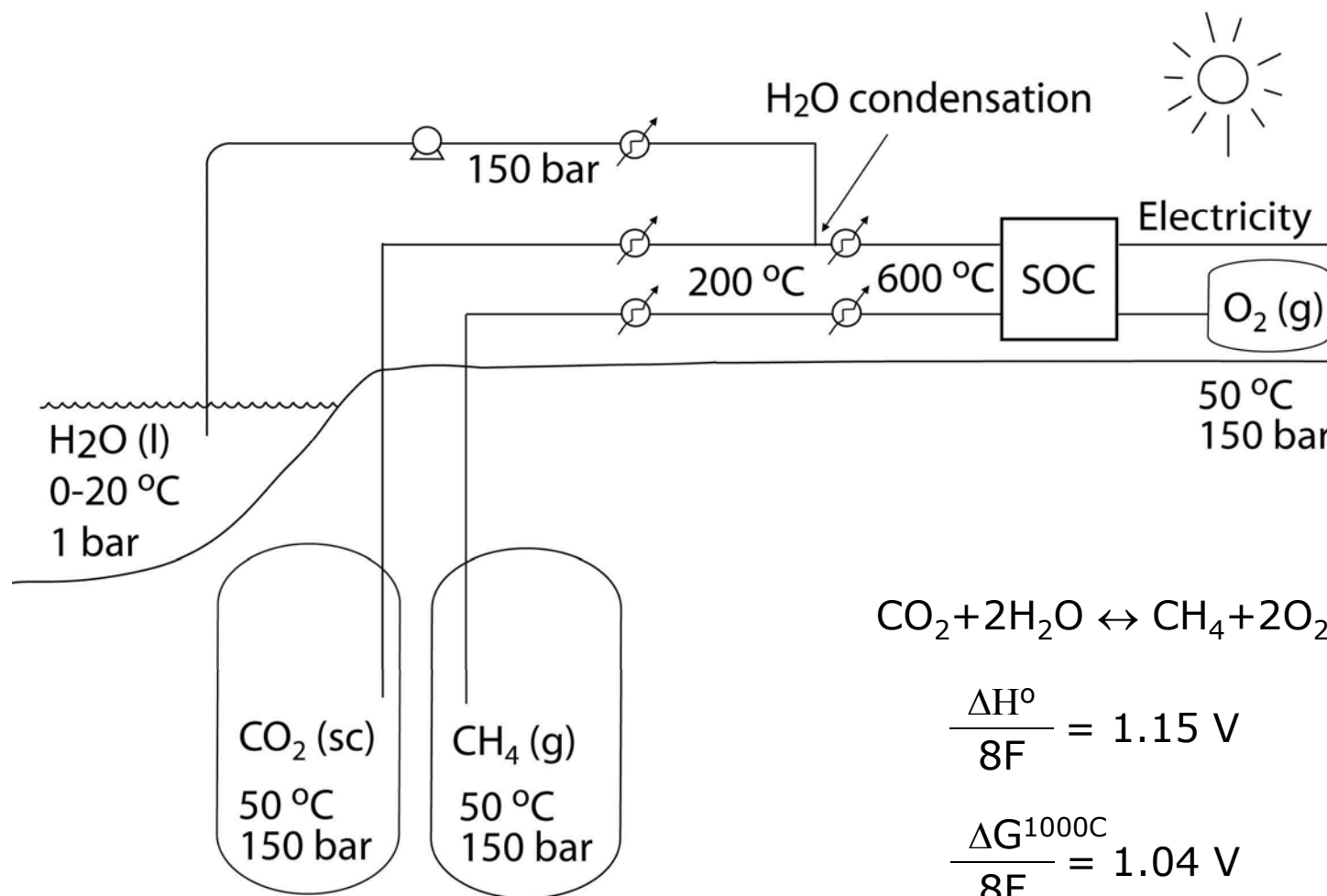
1. **Stable co-electrolysis operation below  $-1 \text{ A/cm}^2$**
2. **Operation at high pressure makes internal catalysis possible which enables high production efficiency**
3. **Using Only Cheap Electricity Doesn't change the synthetic fuel production costs significantly**

# Acknowledgement

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**I wish to thank Colleagues at DTU Energy Conversion for contributions to this presentation**

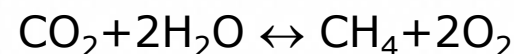
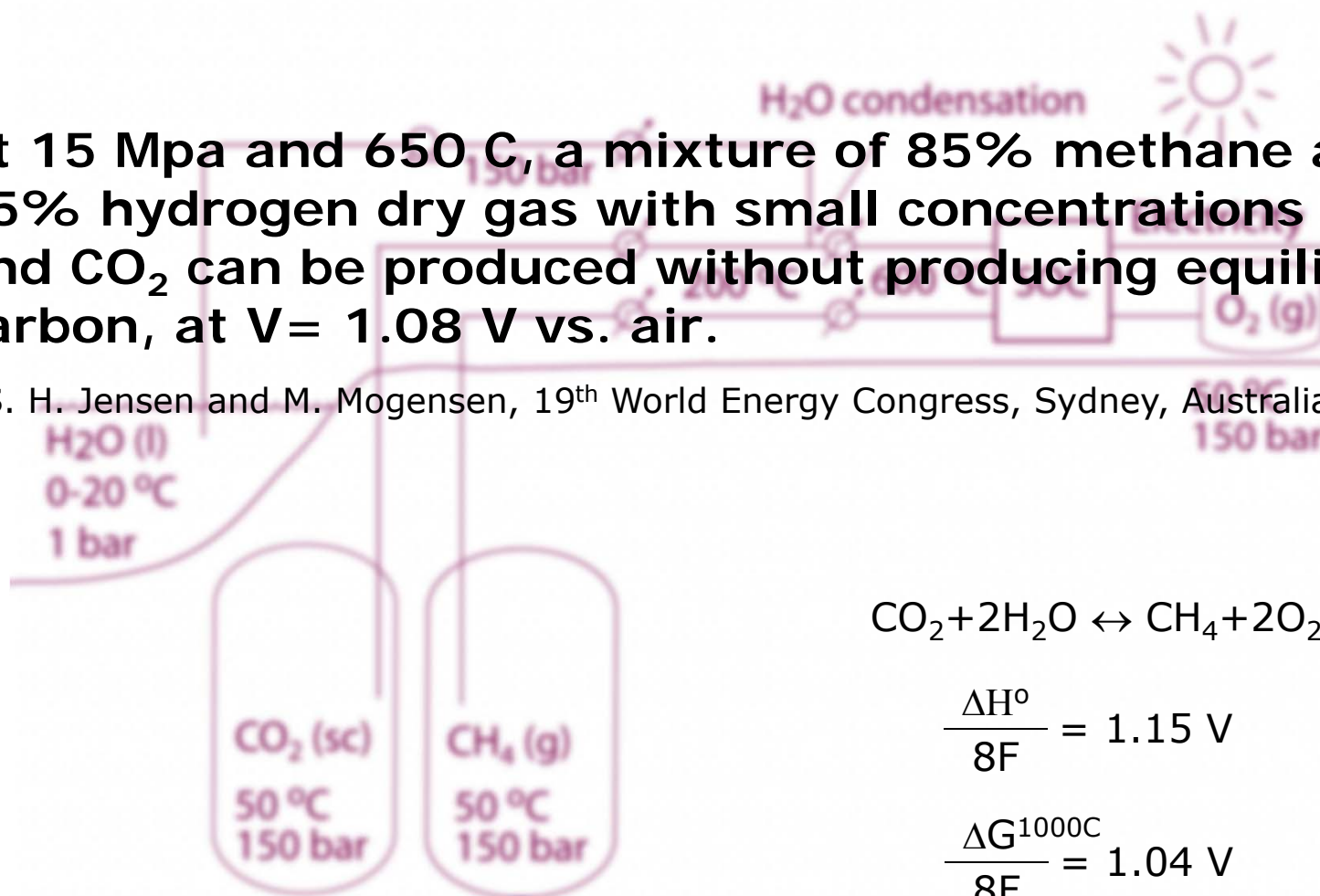
# Vision



# Vision

At 15 Mpa and 650 °C, a mixture of 85% methane and 15% hydrogen dry gas with small concentrations of CO and CO<sub>2</sub> can be produced without producing equilibrium carbon, at  $V = 1.08$  V vs. air.

S. H. Jensen and M. Mogensen, 19<sup>th</sup> World Energy Congress, Sydney, Australia 2004



$$\frac{\Delta H^\circ}{8F} = 1.15 \text{ V}$$

$$\frac{\Delta G^{1000\text{C}}}{8F} = 1.04 \text{ V}$$

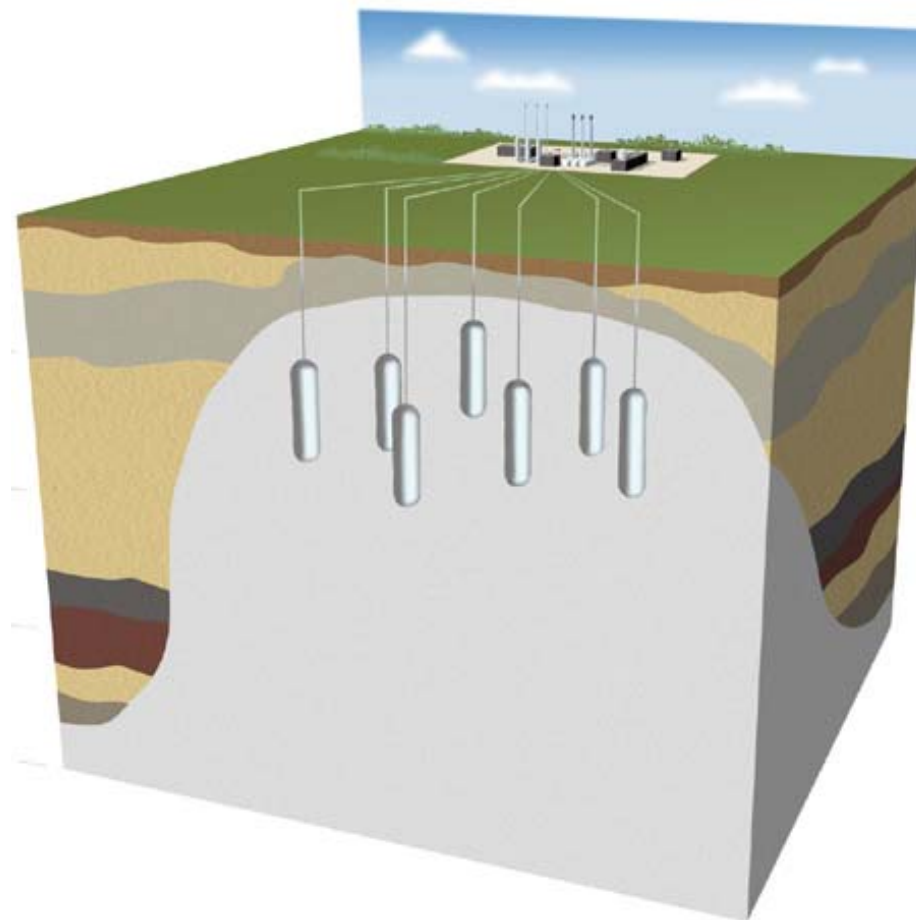


# Vision

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## LI. Thorup Salt caverns

- 150-200 bar
- 500 mill Nm<sup>3</sup> storage
- 5000 mill kWh stored
- 200 M€ CAPEX



# Vision

Operating cost and conditions	
Operating pressure	150-200 bar
Storage capacity (volume)	500 Mio Nm <sup>3</sup>
Storage capacity (Energy (CH <sub>4</sub> ))	5000 GWh
Cavern CAPEX (CH <sub>4</sub> )	200 M€
Cavern CAPEX (CO <sub>2</sub> + CH <sub>4</sub> )	0.08 €/kWh
Electrolysis/Fuel-cell operation/year	4000 hours
SOC cost	150 €/kW
Total SOC CAPEX	200 M€
Total system CAPEX	600 M€ (0.12 €/kWh)

Assume the return of investment on the storage facility is 5 years, the round trip efficiency is 70% and that the storage facility buys electricity during the summer (4000 h) at a cost of 9.6 €/kWh. Then the storage facility will be able to sell electricity during the winter periods (4000 h) for 14 €/kWh.